Calculation By: M. Adamowski
Checked By:
Project No.: LAPD
Date: 11/11/09
Revision: A

Nitrogen coil size for required HX area

The Nitrogen coils are sized to provide excess heat transfer area in excess of the minimum area calculated in LartPC-doc-476-v1. Two coils are used with part of the heat transfer area in the first coil and the remainder in the second coil.

The coil pressure drops are checked for all vapor flow using nitrogen flow split over the two coils.

Nitrogen Data

Nitrogen physical properties from NIST REFPROP

Nitrogen flow (0.7 vapor qual.) from other calc

$$mflow_{N2} := 240 \cdot \frac{lb}{hr}$$

Nitrogen MW

$$MW_{N2} := 28.0134 \cdot \frac{gm}{mole}$$

Nitrogen Vapor Density @ 78 K

$$Vdens_{N2} := 4.56 \cdot \frac{kg}{m^3}$$

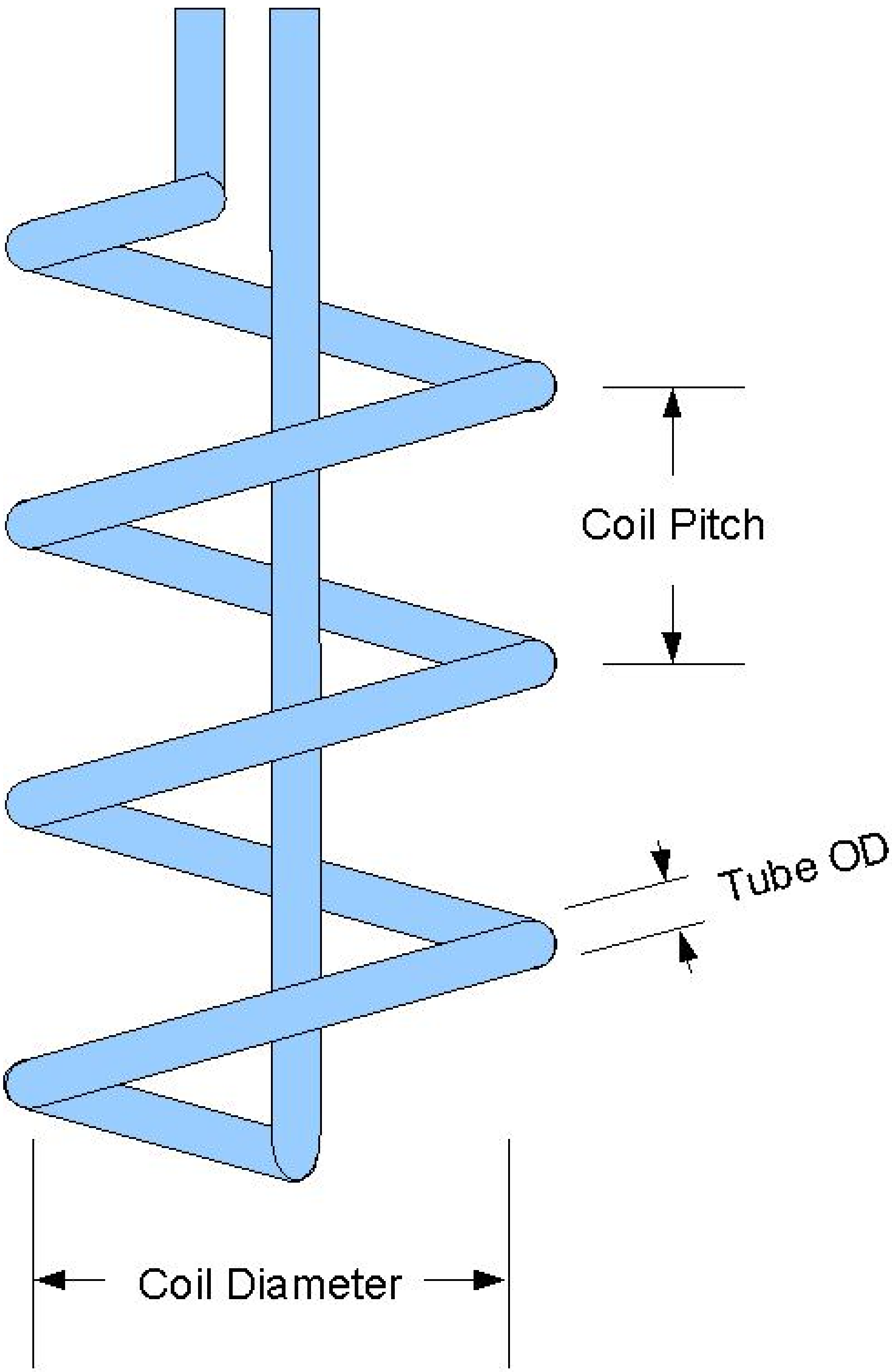
Nitrogen Gas Viscosity @ 78 K and 3 psig

$$\mu_{N2.v} := 0.0561 \cdot cpoise$$

Nitrogen Heat Capacity Ratio @ 78 K

$$\gamma_{N2} := 1.46$$

Illustration of Coil Parameters used in Calculations



HX Area for coil sizing

Minimum heat transfer area from HX calc

$HX_{area.min} := 3.85 \cdot ft^2$

HX Area per Coil

$Coil1_{area} := 3 \cdot ft^2$

$Coil2_{area} := 1 \cdot ft^2$

$Coil3_{area} := 4 \cdot ft^2$

$Coils_{area} := Coil1_{area} + Coil2_{area} + Coil3_{area} = 8 \cdot ft^2$

Tube and Coil parameters

Tubing outside diameter

$Tube_{OD} := 0.625 \cdot in$ 5/8 inch tubing

Tubing wall thickness

$Tube_{wall} := 0.065 \cdot in$

Tubing inside diameter

$Tube_{ID} := Tube_{OD} - 2 \cdot Tube_{wall} = 0.495 \cdot in$

Pipe Roughness:

$\varepsilon := 0.00005 \cdot ft$ roughness factor for smooth stainless tubing

Coil Inside Diameter

$Coil_{inside.dia.1} := 8 \cdot in$

$Coil_{inside.dia.2} := 8 \cdot in$

$Coil_{inside.dia.3} := 9.5 \cdot in$

Coil pitch

$Coil_{pitch} := Tube_{OD} + 0.25 \cdot in = 0.875 \cdot in$

Coil Size Calculations

Coil 1 Tube length

$$Tube_{1.L.req} := \frac{Coil1_{area}}{\pi \cdot Tube_{OD}} = 18.335 \cdot ft$$

Coil 2 Tube length

$$Tube_{2.L.req} := \frac{Coil2_{area}}{\pi \cdot Tube_{OD}} = 6.112 \cdot ft$$

Coil 3 Tube length

$$Tube_{3.L.req} := \frac{Coil3_{area}}{\pi \cdot Tube_{OD}} = 24.446 \cdot ft$$

Coil 1 Number of coil loops

$$Num_{1.turns} := \frac{Tube_{1.L.req}}{\pi\left(Coil_{inside.dia.1} + Tube_{OD}\right)}$$

$$Num_{1.turns} = 8.12$$

Coil 2 Number of coil loops

$$Num_{2.turns} := \frac{Tube_{2.L.req}}{\pi\left(Coil_{inside.dia.2} + Tube_{OD}\right)}$$

$$Num_{2.turns} = 2.707$$

Coil 3 Number of coil loops

$$Num_{3.turns} := \frac{Tube_{3.L.req}}{\pi\left(Coil_{inside.dia.3} + Tube_{OD}\right)}$$

$$Num_{3.turns} = 9.222$$

Coil 1 coil height

$$Coil_{1.h} := Num_{1.turns} \cdot Coil_{pitch} + Tube_{OD}$$

$$Coil_{1.h} = 0.64 \cdot ft$$

Coil 2 coil height

$$Coil_{2.h} := Num_{2.turns} \cdot Coil_{pitch} + Tube_{OD}$$

$$Coil_{2.h} = 0.25 \cdot ft$$

Coil 3 coil height

$$Coil_{3.h} := Num_{3.turns} \cdot Coil_{pitch} + Tube_{OD}$$

$$Coil_{3.h} = 0.72 \cdot ft$$

Coil Pressure drop calc

This coil pressure drop calc does the worst case, which is the longest coil at the tightest coil diameter. The Nitrogen flow is taken as the fraction of the longest coil area versus total coil area. Since doing the pressure drop on vapor only is already conservative no excess N2 is used in the calcs.

define parameters for pressure drop calc

Tube Outlet Pressure
assuming 1 psi back pressure frop vent piping

$P_{out} := 1 \cdot psi + atm$

Outlet Temperature

$T_{out} := 80 \cdot K$

heat capacity ratio

$\gamma := \gamma_{N2}$

molecular weight

$M_w := MW_{N2}$

viscosity

$\mu := \mu_{N2.v}$

mass flow

$$mflow := 0.7 mflow_{N2} \cdot \frac{Coil3_{area}}{Coils_{area}} = 84 \cdot \frac{lb}{hr}$$

massflow for pressure drop is vapor based on coil area ratio and no excess N2

Tube diameter

$D_i := Tube_{ID}$

Tube Length

$L := Tube_{3.L.req}$

define initial guesses for calc

Pressure Drop initial guess

$\Delta P := 1.5 \cdot psi$

Pipe Inlet Pressure

$P_{in} := P_{out} + \Delta P \qquad P_{in} - atm = 2.5 \cdot psi$

Temperature Change initial guess

$\Delta T := 0.01 \cdot K$

Inlet Temperature

$T_{in} := T_{out} + \Delta T$

Friction factor initial guess, straight pipe and coil

$f_{st} := 0.002 \qquad f := 0.004$

Calc Flow parameters to identify flow regime in coil

Calc tube velocity

$$V_1 := \frac{\dfrac{mflow}{Vdens_{N2}}}{\left(\dfrac{D_i}{2}\right)^2 \cdot \pi} = 61.333 \cdot \frac{ft}{s}$$

Calc Reynolds number

$$Re_{num} := \frac{V_1 \cdot D_i \cdot Vdens_{N2}}{\mu} = 19105$$

Calc critical Reynolds number

$$Re_{cr} := 2100 \cdot \left(1 + 12 \cdot \sqrt{\frac{D_i}{Coil_{inside.dia.1}}}\right) = 8368$$

$$flow_{regime} := if\left(Re_{num} > Re_{cr}, \text{"TURBULENT FLOW"}, \text{"LAMINAR FLOW"}\right)$$

$$flow_{regime} = \text{"TURBULENT FLOW"}$$

Calc Deans number for coil

$$Dn_{num} := Re_{num} \cdot \left(\frac{D_i}{Coil_{inside.dia.1}}\right)^{0.5} = 4752$$

The Deans number is only needed if the flow is laminar. Forlaminar flow, the laminar friction factor correlation has to be used.

Pipe Pressure Drop Equations

Given

Fanning Friction Factor
tradional straight pipe

$$\frac{1}{\sqrt{f_{st}}} = -4.0\cdot\log\left(\frac{\varepsilon}{3.7\cdot D_i} + \frac{1.255}{4\cdot\frac{mflow}{D_i\cdot\pi\cdot\mu}\cdot\sqrt{f_{st}}}\right)$$

Coil friction factor for turbulent flow
based on straight pipe friction factor

$$f = f_{st} + 0.03\cdot\sqrt{\frac{D_i}{Coil_{inside.dia.1}}}$$

ref: "Coiled Tubing Hydraulics Modeling", Tech Note by Bharath Rao, May 10, 1999, CTES, L.C., www.ctes.com.

Adiabatic compressible flow equations

$$\frac{mflow}{\left(\frac{D_i}{2}\right)^2\cdot\pi} = \sqrt{2\cdot\frac{M_w}{R_g}\cdot\left(\frac{\gamma}{\gamma-1}\right)\cdot\left[\frac{T_{out}-T_{in}}{\left(\frac{T_{in}}{P_{in}}\right)^2-\left(\frac{T_{out}}{P_{out}}\right)^2}\right]}$$

$$\left[\frac{\gamma+1}{\gamma}\cdot\ln\left(\frac{P_{in}\cdot T_{out}}{P_{out}\cdot T_{in}}\right) - \left(\frac{\gamma-1}{2\cdot\gamma}\right)\cdot\left(\frac{{P_{in}}^2\cdot{T_{out}}^2-{P_{out}}^2\cdot{T_{in}}^2}{T_{out}-T_{in}}\right)\cdot\left(\frac{1}{{P_{in}}^2\cdot T_{out}}-\frac{1}{{P_{out}}^2\cdot T_{in}}\right)\right] + \frac{4\cdot f\cdot L}{D_i} = 0$$

ref: Chemical Process Safety: Fundamentals with Applications. 2nd ed.

$$\begin{pmatrix} f_{st} \\ f \\ T_{in} \\ P_{in} \end{pmatrix} := \mathrm{Find}\left(f_{st}, f, T_{in}, P_{in}\right)$$

Results

Inlet Pressure

$$P_{in} - atm = 4.63 \cdot psi$$

Inlet Temperature

$$T_{in} = 80.063 \cdot K$$

Fanning Friction factor straight pipe

$$f_{st} = 0.007$$

Pressure Drop

$$P_{in} - P_{out} = 3.634 \cdot psi$$

Fanning Friction factor for the coil

$$f = 0.01461$$

N2 Mass flux

The N2 massflux should be close to the N2 massflux for the N2 boiling heat transfer coefficient used in LartPC-doc-476-v1.

Here close is defined as 80%.

Massflux minimum required for minimum HX area

$$N2_{massflux\_for\_h} := 70 \cdot \frac{kg}{m^2 \cdot s}$$

$$Massflux_{N2} := \frac{mflow}{\pi \cdot \left(\frac{Tube_{ID}}{2}\right)^2} = 85.246 \cdot \frac{kg}{m^2 \cdot s}$$

$$Ans := if\left(Massflux_{N2} > 0.8 \cdot N2_{massflux\_for\_h}, \text{"solution is good"}, \text{">>>massflux low <<<"}\right)$$

$$Ans = \text{"solution is good"}$$

LAPD CONDENSER Conceptual Drawing